MODIS Semi-Annual Report
Reporting Period: July - December, 1995
Submitted by: Dorothy K. Hall/974

SUMMARY

Much of the period of July-September, 1995 was spent preparing for the First MODIS Snow and Ice Workshop which was held 13-14 September. Additionally, work continued on processing the passive microwave and MODIS Airborne Simulator (MAS) data that were acquired during the April 1995 field experiment in Alaska. Some uncalibrated data have been acquired. Microwave Imaging Radiometer (MIR) data, also acquired during the April field experiment, were processed and analysis has begun. At least two presentations were made at the snow and ice workshop, and one presentation was made at the MODIS Team Meeting in November, and two papers have been accepted for publication. Two abstracts have been submitted to the IGARSS '96 conference and two have been submitted to the Eastern Snow Conference meeting; both conferences will be held next spring. The snow and ice workshop proceedings has been published. A paper was published in Remote Sensing of Environment.

Additional testing of the SNOMAP algorithm has taken place by comparison on SNOMAP results with results from spectral-mixture modeling.

The beta 3 versions of the snow and sea ice algorithms were delivered to SDST. Complete processing strings for the beta 3 versions of the algorithms, products, I/O test files, supporting files and documentation were delivered.

FIRST MODIS SNOW AND ICE WORKSHOP

The following is the Preface and the Executive Summary written for the Proceedings of the First MODIS Snow and Ice Workshop held on 13-14 September, 1995 in Reston, VA and Greenbelt, MD.

Preface

On 13-14 September 1995, a workshop was held in Reston, Virginia and Greenbelt, Maryland at which snow and ice scientists met to discuss the Earth Observing System (EOS) Moderate Resolution Imaging Spectroradiometer (MODIS) snow and ice products. The workshop was sponsored by NASA/Goddard Space Flight Center. The first morning of the workshop was held at the U.S. Geological Survey in Reston in conjunction with the Arctic Climate Systems Study (ACSYS) workshop which, on that day, was focusing on solid precipitation. On the second day, the MODIS snow and ice workshop was held at Goddard Space Flight Center. Thirty six people registered. Eighteen presentations were made dealing with various aspects of snow, ice and snow-cover mapping. During the remainder of the second day, attendees participated in one of four working groups, each of which discussed different aspects of MODIS snow and ice products. During the working group sessions, participants also discussed a set of questions provided to them at the beginning of the workshop. The chairperson of each working group summarized results at the end of the workshop in the closing plenary session.

Executive Summary

The objectives of the First MODIS Snow and Ice Workshop were to: inform the snow and ice scientific community of potential MODIS products, ensure that the snow and ice products meet the needs of future users, seek advice from the participants regarding the utility of the products, and determine the needs for future post-launch MODIS snow and ice products.

After hearing descriptions of the algorithm-development efforts from the MODIS snow and ice algorthim-development team, discussions were held regarding the utility of the planned products. At the beginning of the workshop, the snow and ice maps were envisioned to be global, 1-km daily and weekly-composited maps, with snow and ice (both sea ice and ice on large, inland lakes) being identified using an algorithm that employs thresholding to identify snow or ice. Nearly everyone (both operational and research-oriented people) expressed the desire to have the snow maps at better than 1-km resolution). People who were involved in operational aspects of snow and ice monitoring expressed a desire to receive both snow and ice maps in 24 hours or less, but indicated that a 48-hour turnaround time to produce a product is still useful.

The MODIS snow and ice product development will be modified in the pre-launch time frame as a result of the workshop recommendations. Exact details of the changes will evolve over the next few months. However it has been decided that the snow map and the maps of the large, inland lakes will have 500-m spatial resolution instead of 1-km resolution. Additionally, a scheme will be devised wherein the user can select his/her own time period for compositing. In regard to the sea ice product, we will work to implement the sea ice algorithms that were identified during the workshop discussions. Interim results of the algorithm changes will be presented over the next year at scientific meetings.

Brief summaries of the working group recomendations are given below. One theme that was brought out in all of the group discussions was the importance of a good cloud mask. This is considered essential to the successful utilization of the MODIS data. The MODIS cloud mask can be validated with other EOS data, such as the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER).

MODIS At-Launch Snow Products Working Group

There was much discussion about the planned MODIS snow maps. It was generally agreed that daily maps would be useful as would composite maps. However, there was no agreement on the time period of the compositing. People involved in long-term climate studies were interested in monthly snow maps, while others wanted maps composited for a period of a few days or a week. There was also agreement that fractional snow cover is desirable and is possible to accomplish using some image-processing techniques today, in small basins. However, for the production of global maps, these advanced techniques are not yet available. In the pre-launch time frame, when the algorithm has to be finalized, no-one suggested a way to do fractional snow cover globally.

For operational studies, 250-500-m spatial resolution is optimal with a 24-48-hour turnaround time after data acquisition. However, 500-m resolution with 48-hour turnaround is acceptable. The daily snow map is necessary for operational use. A monthly product would be good for climatological studies. It was concluded that the user should decide the compositing period of the daily maps.

MODIS At-Launch Ice Products Working Group

In regard to the sea ice product, the participants concluded that a binary map of sea ice was only marginally useful because RADARSAT synthetic aperture radar (SAR) data are expected to be available in the near future. However MODIS will have better coverage of the Antarctic than will RADARSAT. Additionally, optical data are important and can provide information not available using microwave data. Furthermore, if RADARSAT data are not always available due to failure of the satellite or the sensor, it would be necessary to have other data available. Additionally, optical data can provide information not available using microwave data, especially when the sea ice is wet. Furthermore, thermal-infrared data, to be available on the MODIS, can also provide sea ice temperature, which cannot be obtained using microwave data.

While it was generally agreed that optical data were important for sea ice studies, it was concluded that ice type and concentration information was needed as well as information on the location of sea ice. The group identified a sea ice algorithm, developed by Koni Steffen, that may be useful for that purpose. The group concluded that 1-km spatial resolution is adequate for sea ice studies.

In regard to large inland lakes, discussion indicated that 500-m resolution daily maps would be useful and an important advance over the 1-km resolution data that are currently available.

Post-Launch MODIS Snow and Ice Products

For a post-launch snow product, subpixel snow mapping is needed at local and regional scales. Additionally, combining Multi-Angle Imaging Spectroradiometer (MISR) and MODIS data, and utilizing the pointing capabilities of the MISR, may increase accuracy of snow mapping in forests. In a post-launch product, albedo, temperature and wetness are also desired.

For sea ice, knowledge of albedo, surface temperature, open water fraction, ice type and ice motion are desired.

There was also a discussion about gridding. The group concluded that the planned use of the International Satellite Cloud Climatology Project (ISCCP)-derived grid for EOS Level 3 products may not be suitable for polar applications of the MODIS snow and ice products. More information is needed to determine the best approach (one that is efficient while preserving scientific integrity) to routinely produce these data for the polar community.

Utility of MODIS Snow and Ice Products
MODIS snow and ice products will be useful for input to snowmelt-runoff models, to validate other sources of snow data, for ice navigation, for ice-jam monitoring, and to study air/sea interaction among other things. A monthly snow or ice product would be useful for climatologists. MODIS data will likely be useful for operational needs especially if 250-m and 500-m resolution data are available within 48 hours.

Additionally, the MODIS data will be especially useful when combined with other data, such as passive-microwave data for determination of snow water equivalent.

Metadata that will be required with the snow and ice products include information on: georeferencing, ephemeris data, calibration and orbit parameters and information on quality of data.

RESEARCH RESULTS

Alaska Mission (April 1995)

Microwave Imaging Radiometer (MIR) data from the 8 flights over Alaska and the Beaufort Sea have been processed, displayed, and analysis has begun. DEM and SSMI data have been registered to the MIR data so that effective comparisons can be made between scenes. Additionally, the MIR data has been placed on the SSMI grid so that comparisons with SSMI data will be facilitated. Very preliminary results show that there are significant changes in brightness temperature between flights, and that the brightness temperature patterns correspond, in many cases, with the patterns observed on the registered SSMI data.

The MODIS Airborne Simulator (MAS) data are still being calibrated by the Project. We have acquired one sample data set of one of the flights over the Fairbanks area. With those data we are in the process of registering a DEM to the MAS data.

MODIS SNOW AND ICE ALGORITHM AND DATA PRODUCT DEVELOPMENT

Complete processing strings for the beta 3 versions of the algorithms, products, I/O test files, supporting files and documentation were delivered. (As of December 1995 the deliveries are still in formal acceptance procedures.) Computer codes for the algorithms were revised to meet project coding standards; SDP and MAPI toolkit functions were integrated into the codes. The algorithms were also revised to incorporate changes decided upon based on interactions with other MODIS algorithm developers, team meetings, and from recommendations that emerged from the First Moderate Resolution Imaging Spectroradiometer Snow and Ice Workshop.

Snow cover algorithm code for products MOD10_L2, MOD10_L2G, MOD10_L3_DY_G and MOD33 were revised and advanced to beta 3 version. Ice extent algorithm code for products MOD29_L2, MOD29_L2G, MOD29_L3_DY_G and MOD42 were revised and advanced to beta 3 version.

MODLAND - SDST Workshop, 25-27 July 1995

G. Riggs participated in the MODLAND-SDST workshop held at Boston University, 25-27 July. He presented and discussed the state of development of the MODIS snow cover and ice extent algorithms and data products. He participated in a discussion of gridding issues and laying out of a modified schedule of algorithm deliveries.

MODIS Cloud Masking Meeting, 18-19 October 1995

G. Riggs presented the snow cover and ice algorithms at the meeting and discussed their relationship and interaction with the MODIS cloud mask algorithm. The cloud mask data product is an expected input into the snow cover and ice extent algorithms. Ideas for improved interrelationships of the algorithms and how to best make use of information from one algorithm in the other algorithm were discussed. Action items were identified and plans laid for synergistic development activities. Responses were made to those action items. Synergistic development activities are continuing among algorithm groups.

Comparative Study of Snow Identification Algorithms

A comparative study of snow and ice classification techniques employed in the MODIS snow cover and ice extent algorithms with the techniques employed by Ron Welch, SDSMT for classification of snow, ice and clouds in Landsat TM data of polar regions was undertaken. A suite of C programs for preprocessing data was written and procedures for comparative analysis were formed. An integrated version of the MODIS snow cover and ice extent algorithms was written specifically for this comparative study. A land/water mask was manually generated for the TM images used in the comparison. The objective of comparative study is to identify strengths and weaknesses of the MODIS algorithms and validate the techniques used. Over 20 TM scenes have been included in the study. Preliminary results and next analysis steps have been discussed among the collaborators. The study continues to progress and an abstract discussing preliminary results has been submitted to the Eastern Snow Conference.

Responses to MODIS SDST

Various requests for information about the MODIS algorithms and data products were received from the MODIS SDST. In general the requests were for information regarding development state, data size and volume, and revisions to specifications of the algorithm codes and data products. Those requests were responded to promptly.

MODIS Snow and Ice Algorithm and Data Product Development

Culmination of algorithm development efforts during this time period was the delivery of the beta 3 versions of the algorithms and data products to the SDST. Complete processing strings for the beta 3 versions of the algorithms, products, I/O test files, supporting files and documentation were delivered. (As of December 1995 the deliveries are still in formal acceptance procedures.) Computer codes for the algorithms were revised to meet project coding standards, SDP and MAPI toolkit functions were integrated into the codes. The algorithms were also revised to incorporate changes decided upon based on interactions with other MODIS algorithm developers, team meetings, and from recommendations that emerged from the First Moderate Resolution Imaging Spectroradiometer Snow and Ice Workshop.

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Assessment of Spectral Mixture Analysis for Development of a Global Snow Cover Mapping Algorithm (Anne W. Nolin)

I. Introduction

The spatial distributions of snow cover and seaice is needed for climate models, where surface albedo is used as a lower boundary condition, and for snowmelt/runoff models, in which snow-covered area is needed for spatially-distributed melt calculations.
One of the fundamental difficulties in producing estimates of snow-covered area using remote sensing techniques has been distinguishing snow from other surface covers in a scene. A second major difficulty lies with the mixed pixel effect that arises from the spectral input of different materials (snow, vegetation, liquid water, etc.) in the sensor field-of-view. Binary classifications from remote sensing data categorize pixels as either completely snow-covered or completely non-snow-covered (Rango,1985; Dozier et al., 1987; Martinec and Rango, 1987; Dozier et al., 1989a). This simplistic approach may introduce large errors in the estimation of snow covered area, particularly in regions where and at times when snow cover is patchy and discontinuous.

In previous work, Spectral Mixture Analysis (SMA), was successfully used to map the subpixel snow cover in satellite and airborne multispectral imagery (Nolin et al., 1993; Rosenthal, 1993; Nolin, 1995). Briefly, SMA uses a linear mixing model in which the sensor response for an image pixel is expressed as a linear combination
of the fractional quantity of each component present in the pixel. In a multispectral image each pixel is modeled as a linear combination of components identified for that image.
Such image components are termed "endmembers" and they are thought to be representative of a finite set of spectrally-unique ingredients in the image. While clearly a successful technique, the primary drawback to the SMA method is that the number and type of spectral endmembers in an image must be known or otherwise deduced in an interactive manner. This constraint prevents SMA from being developed as an operational technique for regions where spectral endmembers are not known.

As part of NASA's Earth Observing System (EOS) project, MODIS will be used to collect data in 36 channels (19 visible and near-infrared channels). Digital maps of global snow covered area will be produced from MODIS data starting with the launch of EOS in 1998.
For this task, a global snow-mapping algorithm, SNOMAP, has been developed (Hall et al., 1994; Hall et al., 1995}.

The empirically-based SNOMAP approach uses the normalized difference snow index (NDSI) and a selected threshold to produce a binary classification of snow cover.
This two channel index, currently being tested with Landsat Thematic Mapper (TM) data, makes use of the fact that snow reflectance is high in the visible and low in the near-infrared. For the MODIS instrument, with spatial resolution ranging from 250-1000 m, it is unlikely to have a pixel that contains only snow or not-snow as assumed in this binary classification and errors resulting from misclassification could be large.

It is the overall goal of this research to assess the efficacy of the SNOMAP algorithm and a related sea ice mapping algorithm (ICEMAP), currently under development.
Towards this end, the following were identified as the specific objectives for this phase of the research:

1. Evaluate automated spectral mixing techniques for mapping snow cover in heterogeneous terrain

2. Assess techniques for snow-cloud discrimination on a pixel-by-pixel basis

3. Examine and assess multi-image spectral unmixing for mapping snow and ice

II. Approach

A. Snow Cover mapping

An alpine region of Glacier National Park, Montana was used as the test region in this snow cover mapping case study. A Landsat Thematic Mapper image of the area was acquired on March 14, 1991. The image area is characterized as rugged, mountainous terrain containing snow, alpine and subalpine vegetation rock areas.
The TM data were first converted from raw digital number values using the appropriate gains and offsets. Atmospheric correction was then performed using the 5S code to convert to data to apparent reflectance. Because of storage and image processing limitations, a 2500x2500 pixel subset of the image was used; this represents an area of about 5625 km^2. Endmembers in each image were determined using principal components analysis and the SMA algorithm was run using the minimum number of endmembers that would still provide a low RMS error.

B. Mapping Sea Ice Concentrations

The SMA model was also used in to test its ability to perform sea ice mapping. Because an index-based ICEMAP algorithm is still in the process of development, comparisons with the SMA approach will be performed in future work.
For this part of the research, a pair of Landsat TM images from the Beaufort Sea region of the Arctic were used to map sea ice concentrations using spectral mixture analysis. The images, acquired on April 16, 1992 and April 18, 1992, are centered on 72.2 N, 145.5 W and 72.2 N, 142.3 W, respectively. File sizes are 5375x4868 pixels for the 16th and 2873x4109 pixels for the 18th. As with the alpine snow images, a principal components analysis was run to determine the endmembers for each image. Both images show the pack ice in spring and open water is visible in the cracks between large pieces of sea ice. No wet snow is visible in the April 16 image but, in the April 18 image, melt is just beginning to occur in the snow overlying some of the sea ice. Some clouds are visible in the bottom and the very top of the April 18 image.

III. Results

A. Comparison of SMA and SNOMAP Results

In a previous document (Final report for Phase Two), the results of a snow covered area calculation for the Glacier National Park TM image using both the SMA and SNOMAP methods agreed to within about 4%. The SNOMAP binary classification resulted in a total snow covered area of 3979 km^2, slightly exceeding the SMA-derived snow covered area estimate of 3820 km^2. At first glance, this close agreement between the results from the two methods is encouraging, however a closer examination reveals several important discrepancies. In this section, I discuss areas of agreement and disagreement between the two methods, the magnitudes of various errors of omission and comission misclassifications, and possible physical explanations for these errors.

1. Pixels with Low Snow Cover

One of the important questions that need to be addressed is: How does the SNOMAP algorithm, with its binary classification approach, perform in areas with partial snow cover? This is especially important for pixels where snow cover is less than 50% since a pixel that is classified by SNOMAP algorithm as snow-covered is considered to have 100% snow cover. Repeated classification of partially-snow covered pixels would result in systematic overestimation of snow covered area for the image.

Comparing pixels classified by the SMA method with those from SNOMAP, it appears that there is a significant amount of the image that is misclassified in various ways. SMA results show that nearly 45% of the image pixels have less than 1/3 snow cover yet were mapped as being completely snow-covered by the SNOMAP algorithm (Table 1). In addition, nearly one-quarter of the image pixels contained significant snow cover (>25%) according to the SMA results, yet these pixels were mapped as non-snow covered by SNOMAP. Figure 1 depicts the various misclassified pixels in red (pixels containing greater than 25% snow but mapped by SNOMAP as having 0% snow), green (pixels having from 25-30% snow cover but mapped as 100% snow covered by SNOMAP) and blue (pixels having from 30-35% snow cover but mapped as 100% snow covered by SNOMAP). It is curious that in some regions of partial snow cover, SNOMAP maps pixels containing low snow amounts as 100% snow while in other areas, with similar partial snow cover, pixels are mapped as non-snow-covered. While not shown here, it turns out that many of the pixels containing greater than 25% snow and identified by SNOMAP as non-snow-covered, also contained significant proportions of shadow. This partial shading of partially snow-covered pixels may be responsible for these areas being mapped as snow-free.

These results point to a potentially serious problem with the SNOMAP algorithm, that is, simultaneous over- and underestimation of snow cover in image pixels. So, while the cumulative snow covered area results from SMA and SNOMAP appear to be in close agreement, the spatial variability shows significant disagreement between the two methods.

Table 1. SNOMAP Misclassification Statistics from Glacier NP Image

Description	Misclassified Pixels	% of Image	Area (km^2)
Snow cover >25% and SNOMAP = 0%	1529466	24.5	1376.5
Snow cover 25-30% and SNOMAP = 100%	1489695	23.8	1340.7
Snow cover 30-35% and SNOMAP = 100%	1327431	21.2	1194.7
Cloud cover >60% snow cover <40% and SNOMAP = 100%	420413	6.7	378.4
Veg cover >60%, snow cover <40% and SNOMAP = 100%	43108	0.7	38.8

2. Cloud-Snow Discrimination

Thin to moderate cloud cover is present in a portion of the 2500x2500 pixel TM image of Glacier National Park. >From the SMA results we can see that the region of greatest cloud concentration is in the southeastern portion of the test image. In this image, a substantial number of pixels with greater than 60% cloud cover and less than 40% snow cover were identified by the SNOMAP algorithm as being completely covered by snow (see Table 1 for details). Figure 2 shows the spatial distribution of cloud fraction and SNOMAP snow cover. In this figure, red pixels are those mapped as snow by SNOMAP and green pixels are those with cloud cover -- thus, yellow pixels are those that have a significant amount of cloud cover but were misclassified by SNOMAP as snow.
While not all cloud pixels were misidentified as snow, in this case study, the comparison with SMA results indicate that this error of comission appears to be a problem with the SNOMAP algorithm. One physical explanation of the differences between the abilities

of SMA and SNOMAP to discriminate between snow and cloud is that SMA makes use of the shape of the spectral signature of an image component such as cloud or snow whereas, the index method uses the relative magnitudes of the spectral reponse in only two channels. The additional channels used by the SMA method and the reliance on shape rather than relative magnitude (which can be influenced by changes in solar illumination)
provides greater ability to discriminate. Indeed, this improved discrimination is true, not only for clouds and snow, but for other spectrally unique and detectable image components.

B. Sea Ice Concentrations using SMA

Without additional concurrent data, it is not possible to know the number and types of endmembers in the scene. Thus, the interpretations here are based simply on the results of the PC analysis and the "best fit" to the image data.

Two endmembers fully described the April 16, 1992 Beaufort Sea Image: sea ice and open water. As seen in Figures 3a and 3b, open water and partial ice cover exists in many of the fractures that exist between the large plates of sea ice. RMS error for this unmixing task was about 0.5%.

In the Beaufort Sea TM image from April 18, 1992, four endmembers were found to best characterize the spectral variability in this six-band image: sea ice, open water, cloud, and wet snow. Figures 4-5 show the fractional proportions of each of these endmembers with white pixels having concentrations near unity and dark pixels having the lowest concentrations. RMS error was very low for this unmixing result (~0.4%).

The SMA method appears to map a wide range of sea ice concentrations in this image. The patterns of partial ice cover in many of the fractures suggest either thin ice or uniform concentrations of sea ice in fractures of certain widths. While the meaning of the ice fraction estimates are unclear, it may be possible to relate ice fraction in a pixel to ice type and perhaps to ice thickness. While, currently there is no comparison with estimates of sea ice concentrations and ice types from a SNOMAP-like method, we expect to produce this comparison in the near future.

A second sort of test was performed to determine if endmembers could be transferred from one image to another. Because the two Beaufort Sea TM images are close in both space and time, it was thought that the seaice and liquid water endmembers from the April 18 image could be used to map those components in the April 16 image. Results of this test indicate that image endmembers should not be applied in a universal fashion. The average RMS error for the newly analyzed April 16 image jumped to 10%, an increase of more than one order of magnitude. A likely cause for the discrepancy is the change in atmospheric parameters (as indicated by the increased cloud cover in the later image). When the spectral endmembers become less representative of the spectral variability within a scene, the RMS error increases. This case study demonstrates that for spectral mixture analysis, the endmembers need to be chosen from the image data themselves for best results.

IV. Conclusions

In the case study using the Glacier National Park TM image, comparison of SNOMAP-derived snow covered area produced value 4.2% larger than that calculated using the SMA technique. Though this difference is not particularly large for the 2500x2500 image,
for snowmelt runoff models, it is crucial to have an accurate measure of the spatial distribution of the fraction of snow cover. Thus, for certain applications such as snowmelt runoff modeling in alpine regions, this index-based binary classification may not provide sufficient information on the spatial distribution of snow cover. Areas significant disagreement between the SMA and SNOMAP methods were in mapping clouds and shaded snow. In many pixels in the Glacier National Park image, the SNOMAP method incorrectly identified shaded snow pixels as non-snow-covered while the SMA method mapped them as containing some fraction of snow cover. Also, many pixels
containing a predominance of cloud cover and little snow were mapped as containing 100% snow by SNOMAP.

Perhaps a more important consideration is the possibility that the SNOMAP threshold (currently set at 0.4) may systematically bias the classification results for pixels containing less than 50% snow cover. For example, if a region has a uniformly patchy snow cover such that each pixel in the image had a snow cover fraction of 0.25, the SNOMAP
appears to map these as containing 100% snow. Clearly this problem deserves serious and thorough investigation to identify the conditions where such large misclassifications occur and, if possible, to quantify the systematic errors.

The SMA method appears to be effective for mapping the spatial distribution
of sea ice at a sub-pixel level. This research further indicates the need for study of mapping sea ice at subpixel resolution to relate ice and water fractions
to sea ice types and ice concentrations. Ice, water, snow and clouds were all clearly separable with a good fit between the SMA model and the data as indicated by low RMS error. It is particularly important to distinguish between ice, open water,
and clouds because of the high proportion of cloud cover in the Arctic
during the mid-summer season when sea ice is undergoing dynamic changes.
Because the range of possible spectral endmembers is small in Arctic scenes this technique holds great promise for accurately characterizing the fine-scale spatial distribution

of sea ice, open water, clouds, and snow.

While tests on the transferability of endmembers show that spectral endmembers chose from one scene cannot be used in another, it would be highly valuable to pursue other techniques for subpixel mapping of both ice and snow. Although the SMA method is highly effective in mapping known elements in a scene, because of the need for interactive endmember selection for each image, this technique is remains in a "pre-operational" phase. That is, until automated endmember selection can be carried out in an accurate and
computationally reasonable fashion, the SMA method will not be appropriate for global operational snow and ice cover mapping. Future work on this project will focus on developing an automated endmember selection process and work-in-progress indicates that this is a promising line of research.

Figure Captions:

Figure 1. Comparison of SMA and SNOMAP results for partially
snow-covered areas in the Glacier National Park test image.
Pixels in red are those containing greater than 25% snow but mapped by
SNOMAP as having 0% snow. Green pixels are those having from 25-30%
snow cover but mapped as 100% snow covered by SNOMAP.
Blue pixels are those having from 30-35% snow cover but
mapped as 100% snow covered by SNOMAP.

Figure 2. Comparison of SMA and SNOMAP snow and cloud classifications.
Red represents pixels mapped by SNOMAP as snow-covered.
Green is the cloud fraction from SMA, ranging from 0 to 1.0.
Blue is the snow fraction from SMA, ranging from 1 to 1.0.
Yellow pixels are those mapped by snowmap as having
significant cloud cover but are mapped by SNOMAP as snow.
Areas of bright magenta are where both SNOMAP and SMA
map the pixels as completely snow-covered.

Figures 3a-3b. Fraction images for the Beaufort Sea region,
April 16, 1992. Two endmembers, open water (shown on the left)
and sea ice (shown on the right), were used to
describe the spectral variations in this image.
Varying concentrations of each appear to indicate
differences in ice type and thickness.

Figures 4a-4b. Fraction images for the Beaufort Sea region,
April 18, 1992. Sea ice and cloud fractions are shown here

(left and right, respectively).

Figures 5a-5b. Fraction images for the Beaufort Sea region, April 18, 1992. Open water and wet snow fractions are shown here (left and right, respectively).

PUBLICATIONS AND PRESENTATIONS

Publications:

Hall, D.K., J.L. Foster, J.Y.L. Chien and G.A. Riggs, 1995: Determination of actual snow-covered area using Landsat TM and digital elevation model data in Glacier National Park, Montana, Polar Record, 31:191-198.

Hall, D.K., J.L. Foster, A.T.C. Chang and K.S. Brown, in press: Mapping snow cover during the BOREAS winter experiment, Proceedings of the Eastern Snow Conference, 7-8 June 1995, Toronto, Canada.

Nolin, A., in press: Assessing spectral mixture analysis for global snowcover mapping, abstract for IUGG meeting, 5 July 1995, Boulder, CO.

Hall, D.K., G.A. Riggs and V.V. Salomonson, 1995: Development of methods and analysis of errors for mapping snow cover using Moderate Resolution Imaging Radiometer (MODIS) data, Remote Sensing of Environment, 54:127-140. (**reprint attached**)

Hall, D.K. (editor), 1995: Proceedings of the First MODIS Snow and Ice Workshop, 13-14 September 1995, Reston, VA and Greenbelt, MD, sponsored by GSFC. (**copy attached**)

Presentations:

Nolin, A., "Assessing spectral mixture analysis for global snow cover mapping," presented at the IUGG meeting, 5 July 1995, Boulder, CO.

Hall, D.K., "Remote Sensing of Snow Cover," presented at the combined MODIS/ACSYS workshop, 13 September 1995, Reston, VA.

Nolin, A., "Mapping Fractional Snow Covered Area and Sea Ice Concentrations," presented at the combined MODIS/ACSYS workshop, 13 September 1995, Reston, VA.

Riggs, G.A., “MODIS Snow and Ice Algorithm Development,” presented at the combined MODIS/ACSYS workshop, 13 September 1995, Reston, VA.

Hall, D.K., “Results of the First MODIS Snow and Ice Workshop,” at the Polar Oceans DAAC Advisory Group Meeting, 17 October 1995, Annapolis, MD.

Riggs, G.A., “MODIS Snow and Ice Algorithm Development,” at the group meeting of the MODIS cloud-masking investigators, 18 October 1995, Madison, Wisconsin

Hall, D.K., “MODIS Snow and Ice Field Experiments,” at the MODIS Team Meeting, 16 November 1995, Greenbelt, MD.